What is light?

… and God said: Let there be

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \boldsymbol{B} = 0$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

$$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} + \mu_0 \varepsilon_0 \frac{\partial \boldsymbol{E}}{\partial t}$$

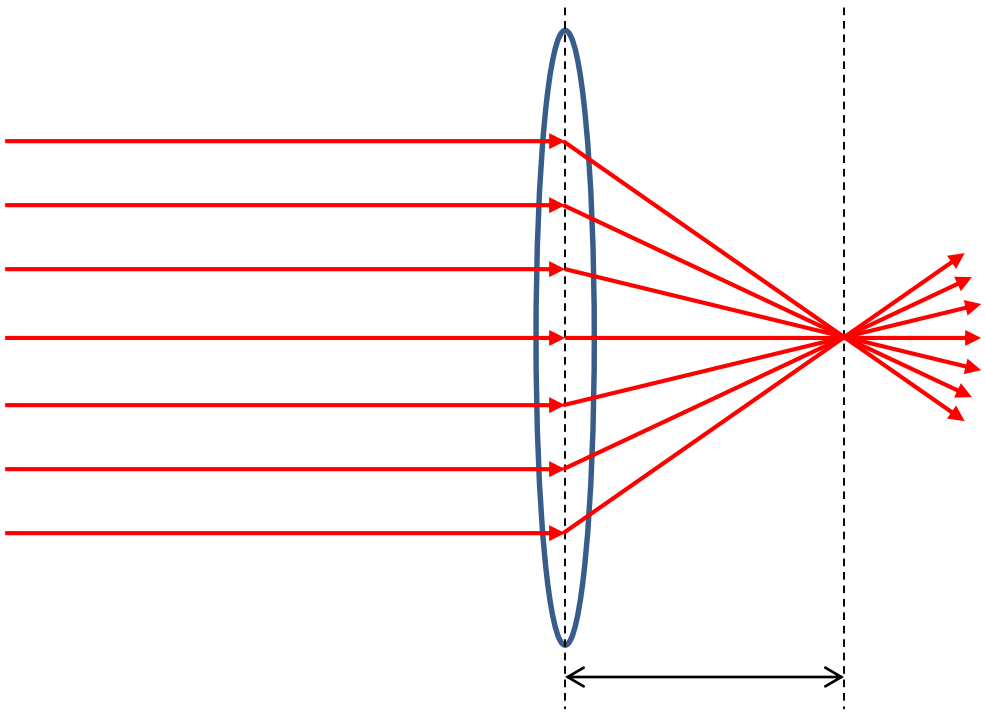
And there was light.

Bo Huang
Dept. Pharmaceutical Chemistry, UCSF


Light as rays

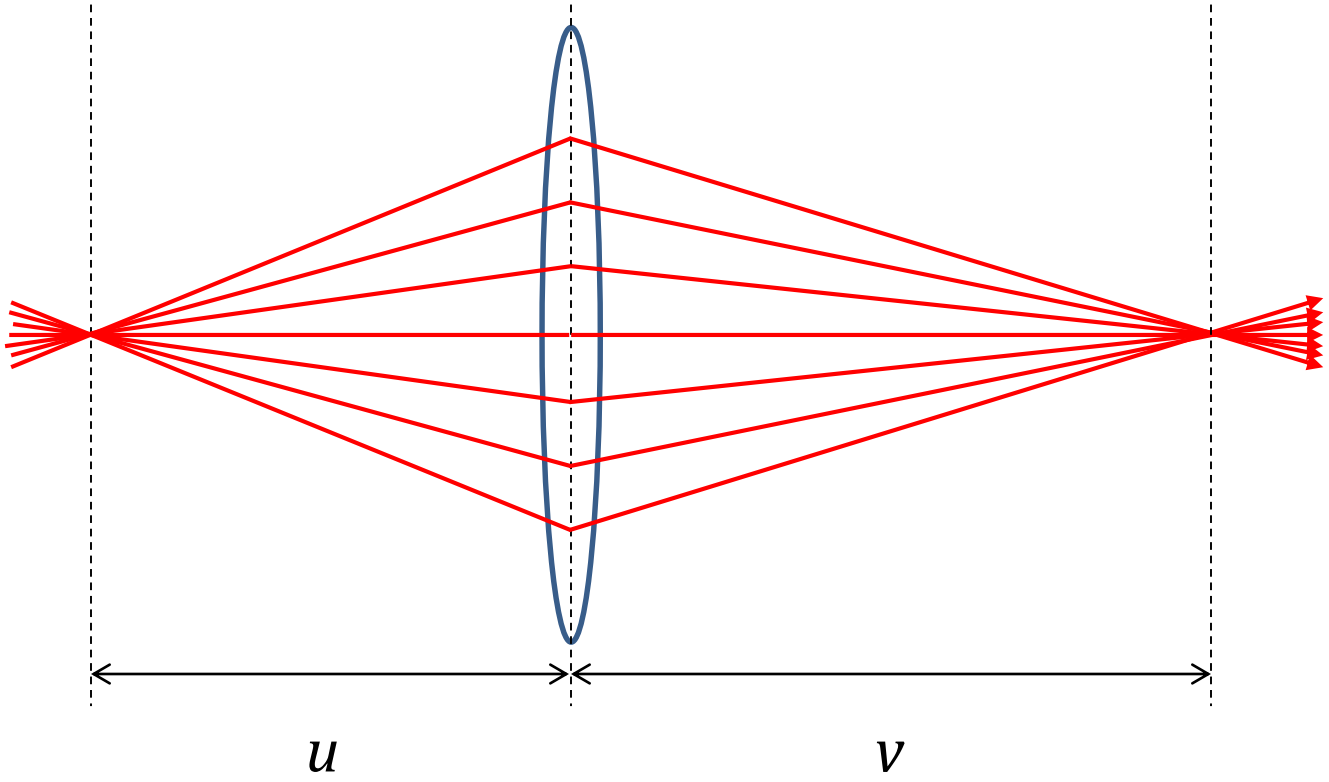
A simple thin lens

A simple thin lens



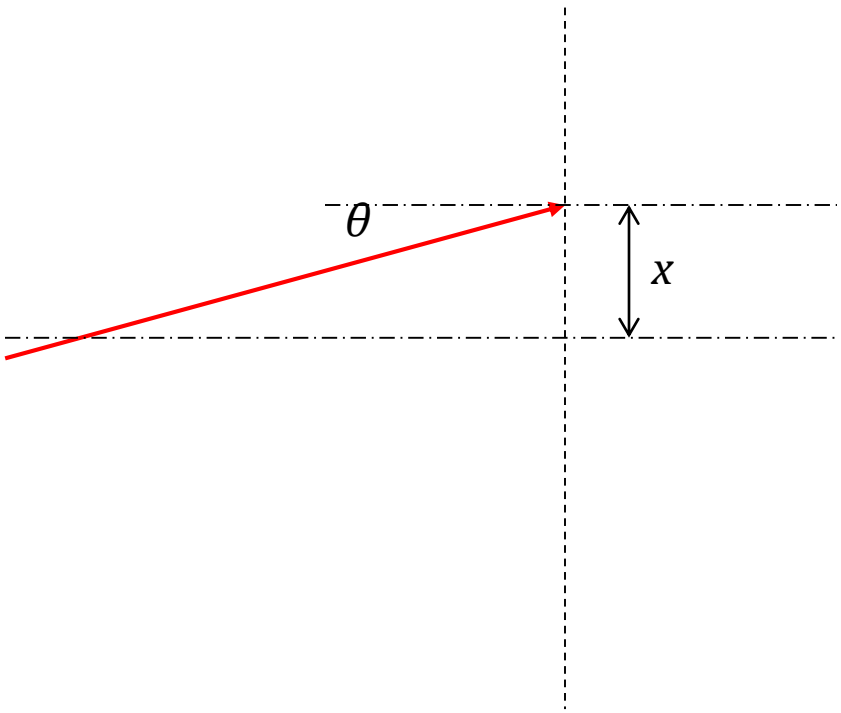
Focal length = f

A simple thin lens

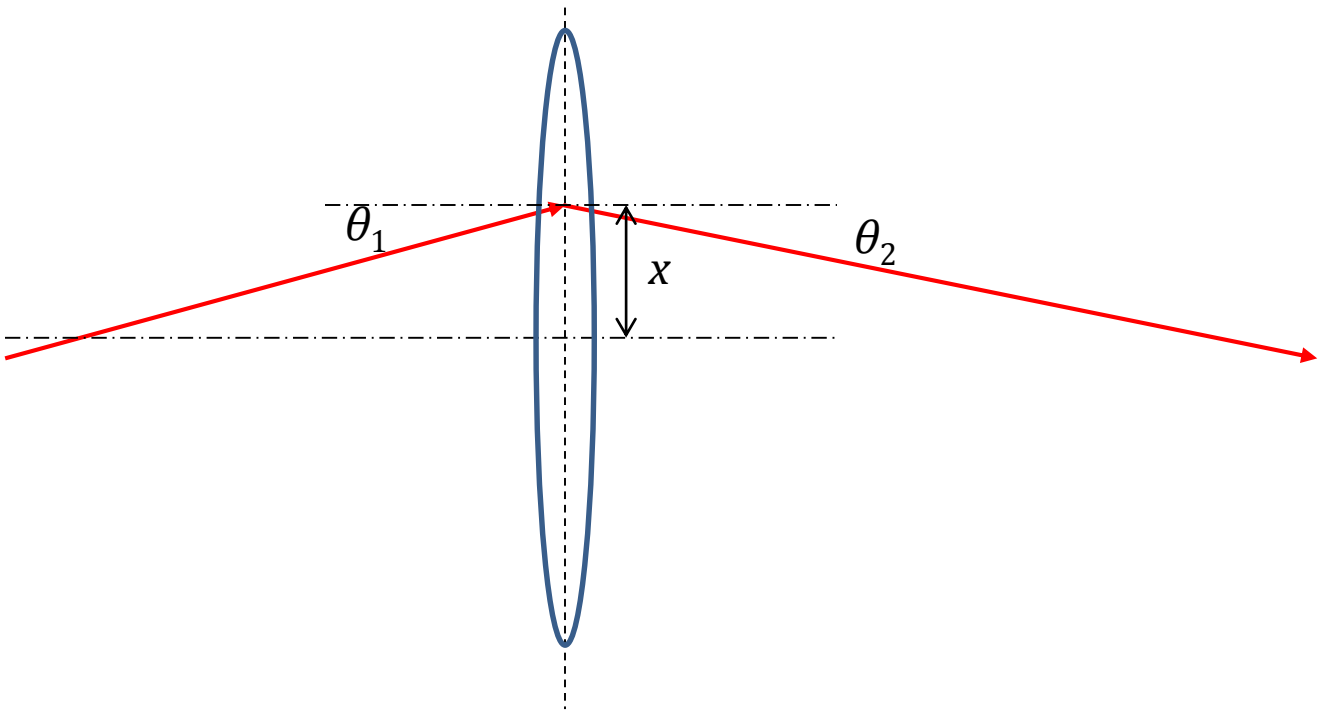


$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Describing a light ray

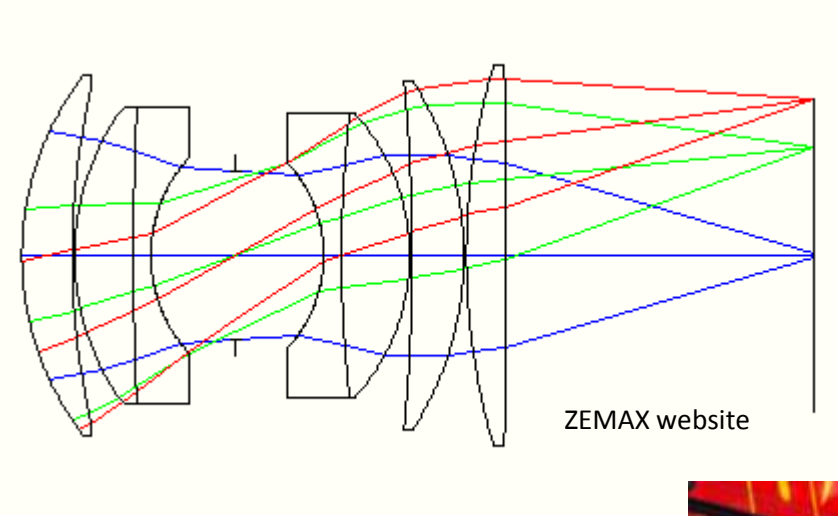


Describing a light ray



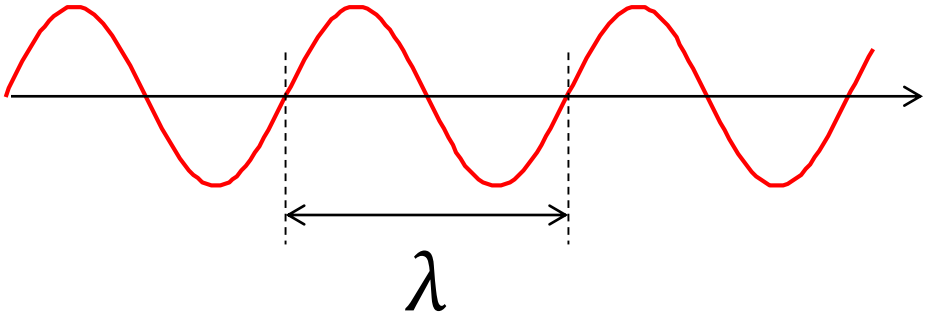
$$(x_1, \theta_1) \Longrightarrow (x_2, \theta_2)$$

Geometric optics and ray tracing



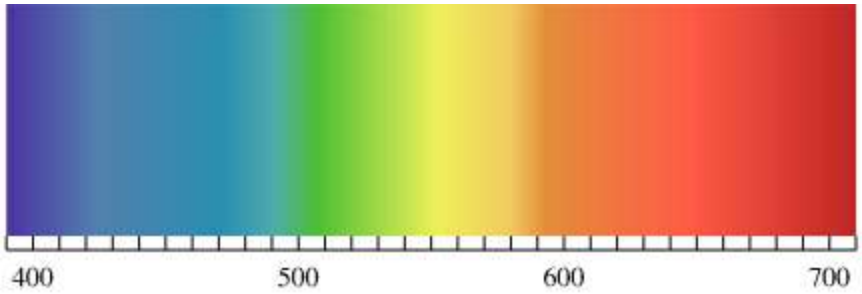
Light as waves

Wavelength and frequency

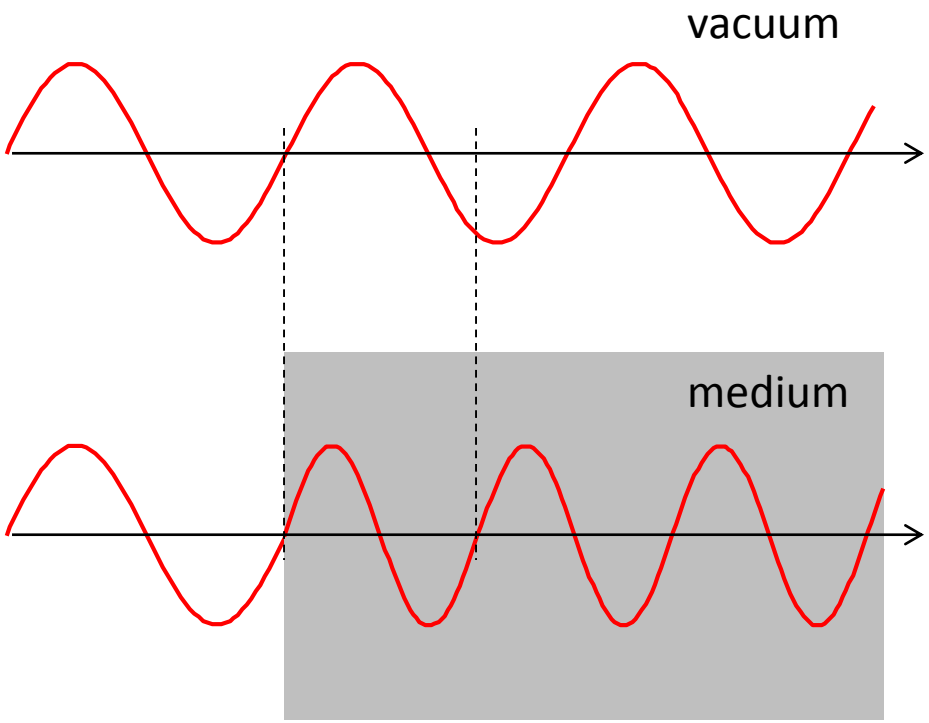


$c = \lambda\nu$

$= 299{,}792{,}458\ \mathrm{m/s}$ in vacuum

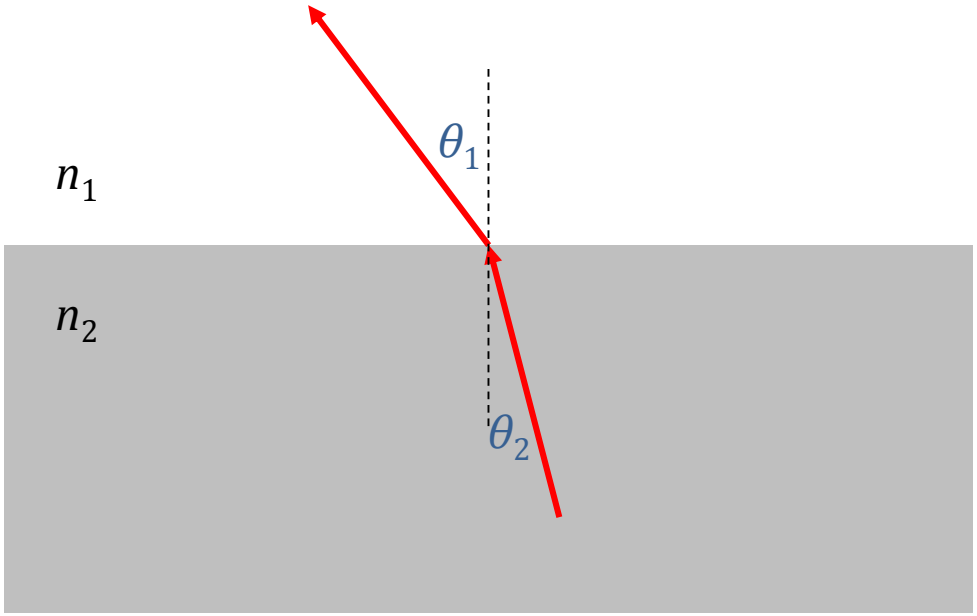


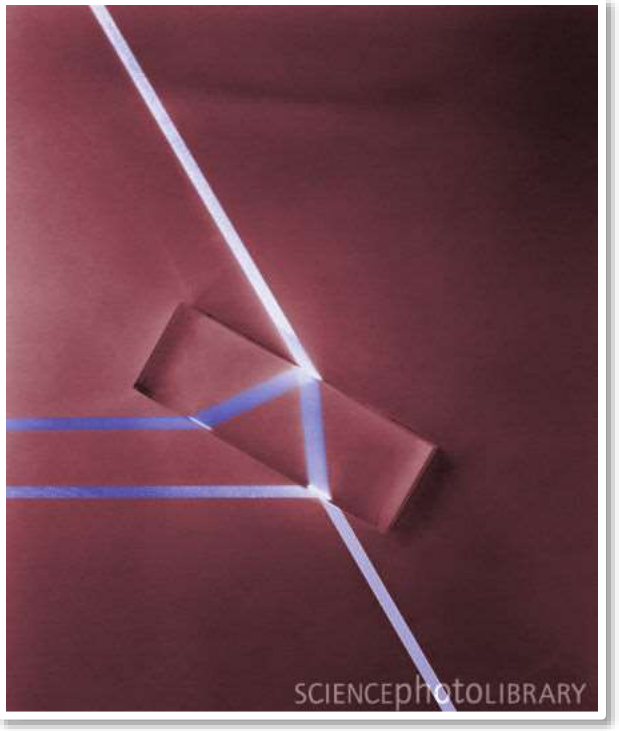
Refractive index



$$n = \frac{c}{\text{speed in medium}} = \frac{\lambda_{\text{vacuum}}}{\lambda_{\text{medium}}}$$

Refraction

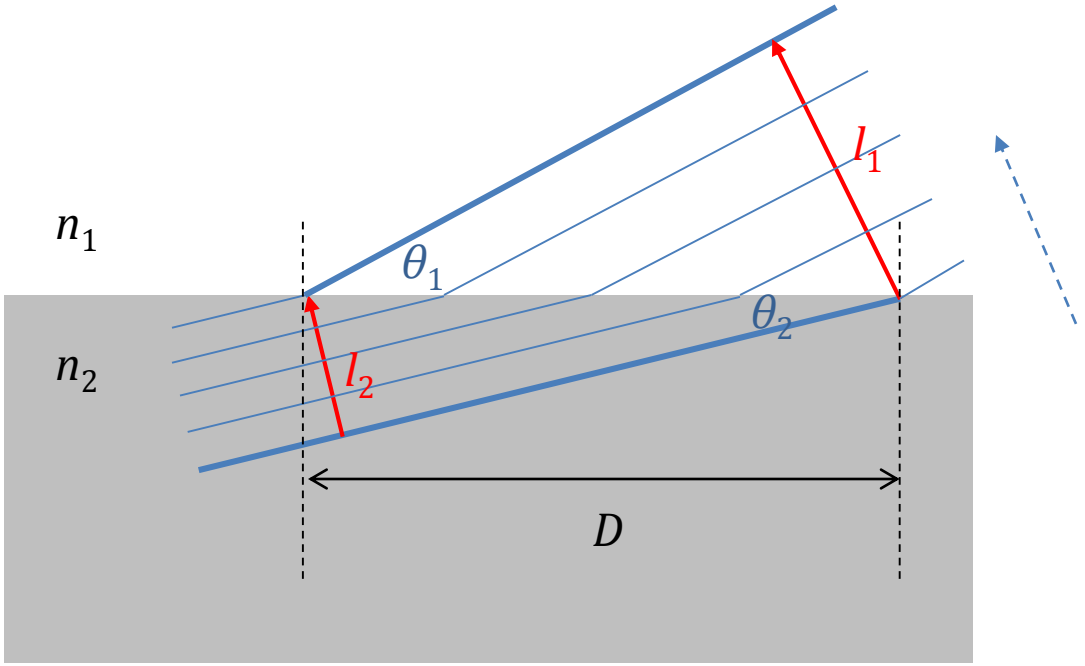




Snell's law:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

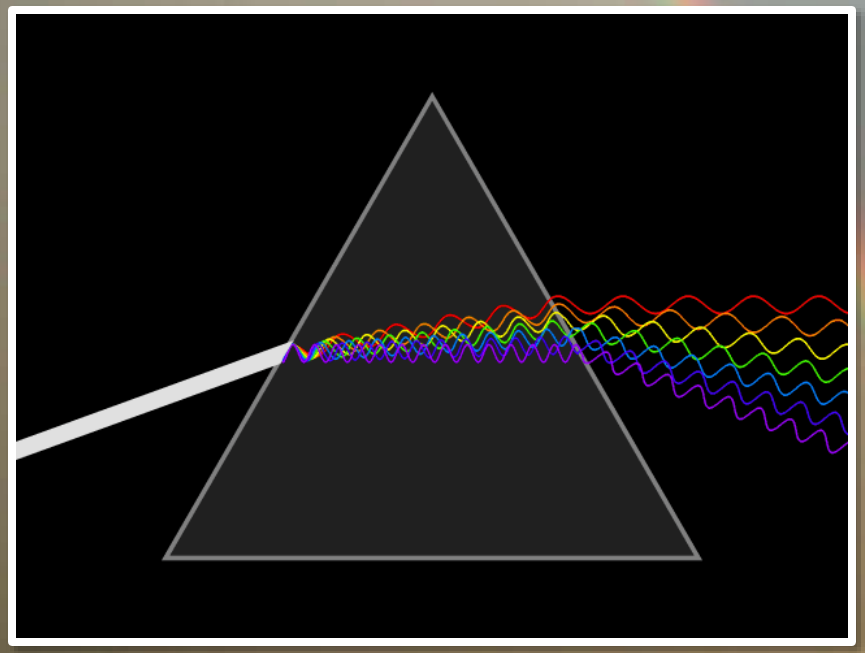
Explaining refraction



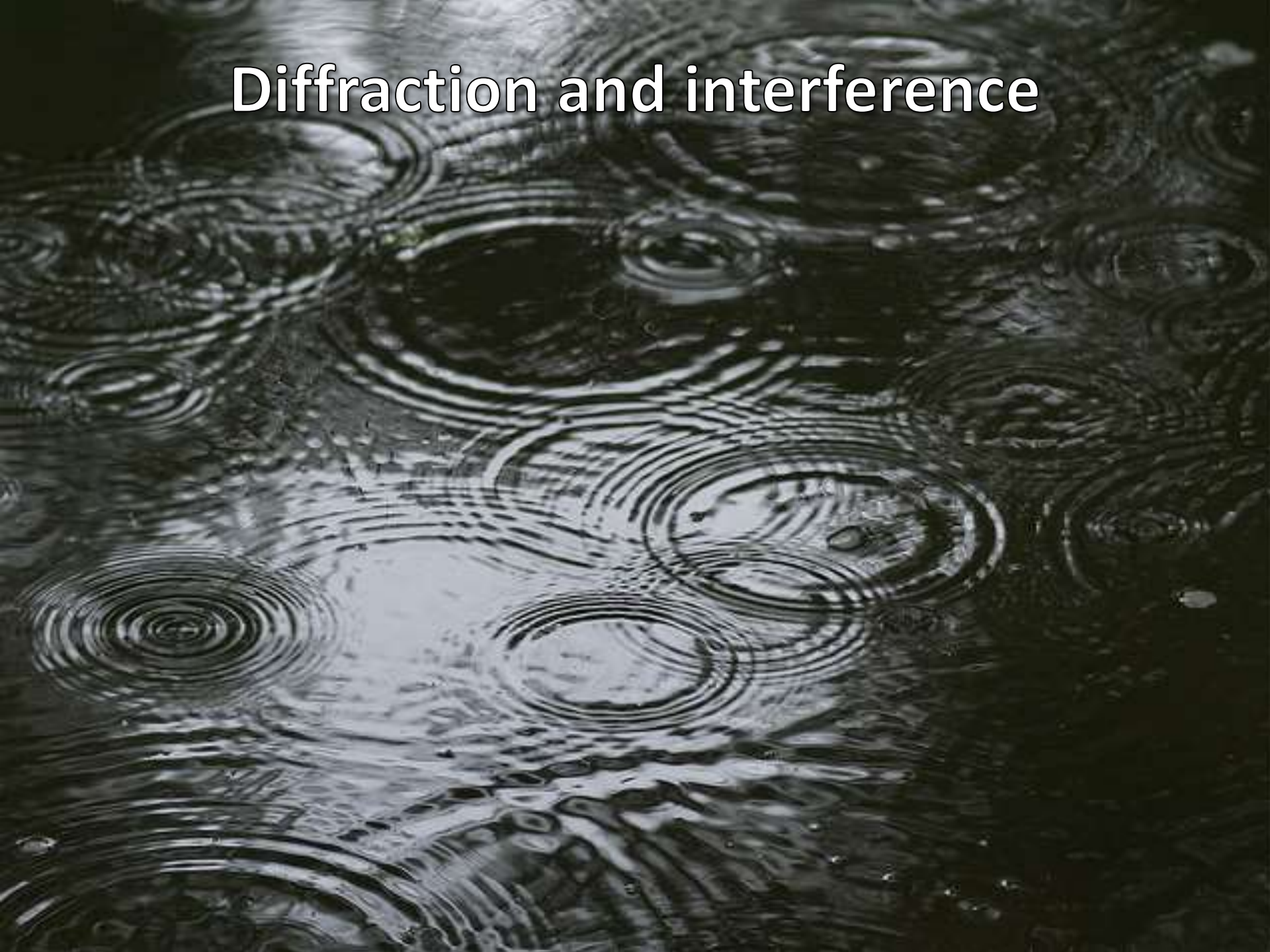
$$\Delta t = \frac{l_1}{c/n_1} = \frac{l_2}{c/n_2} \quad \Rightarrow \quad n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$l_1 = D\sin\theta_1 \qquad l_2 = D\sin\theta_2$$

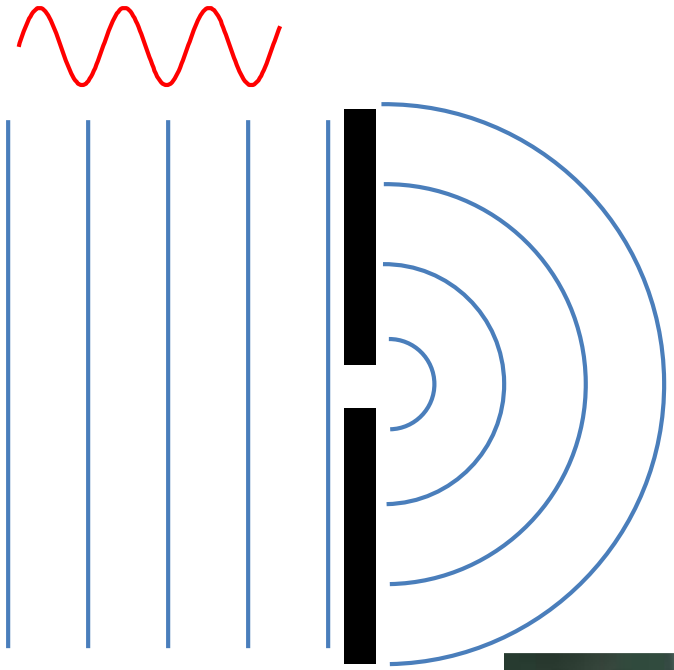
Dispersion



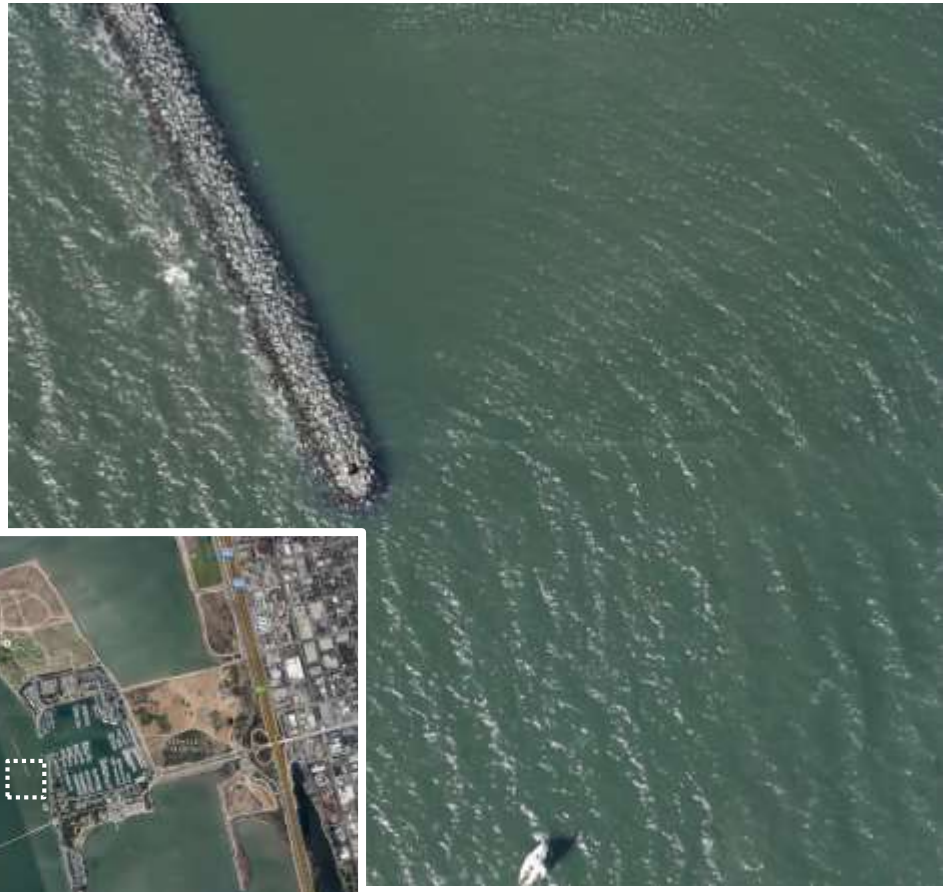
Diffraction and interference



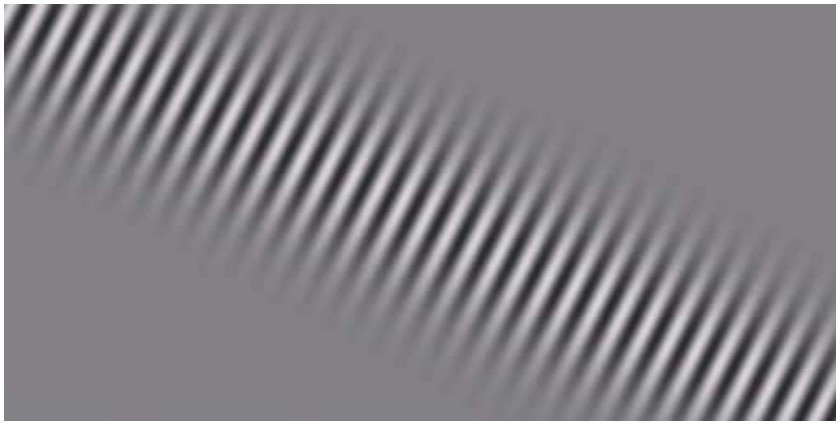
Diffraction



Google Maps



Interference



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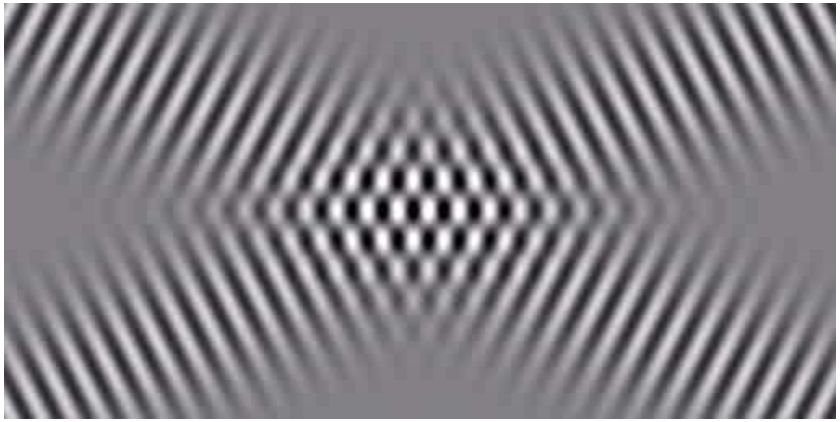
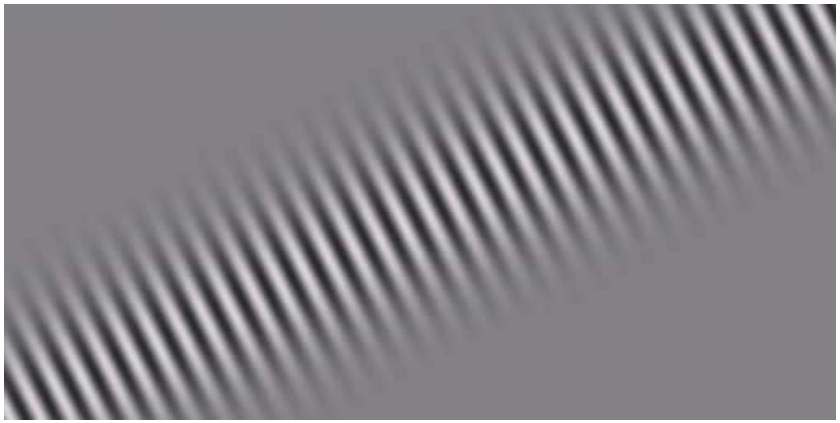
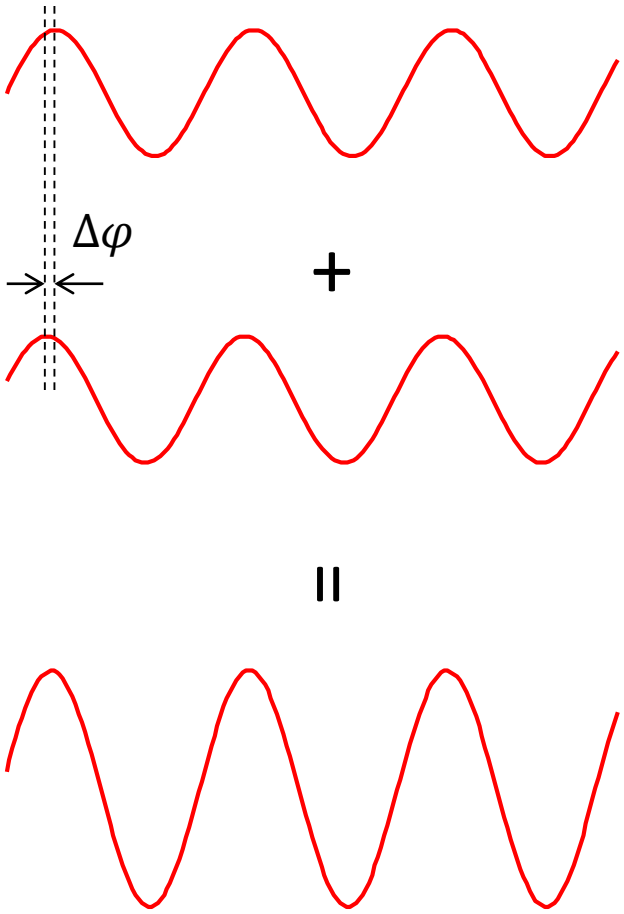
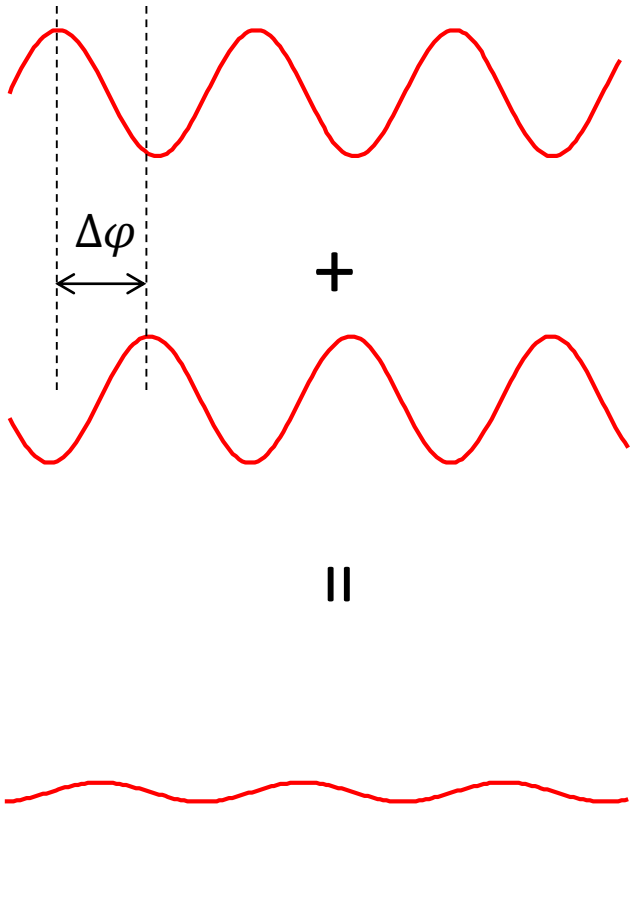




Interference

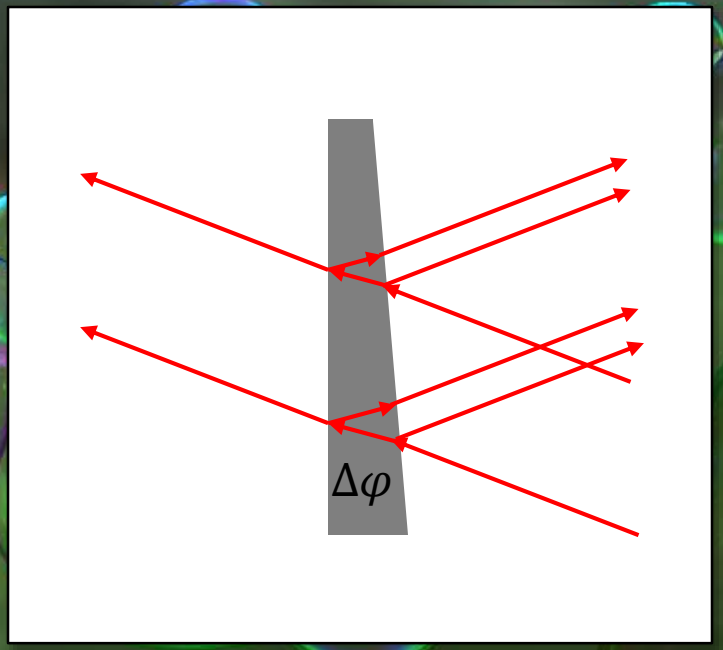


Constructive



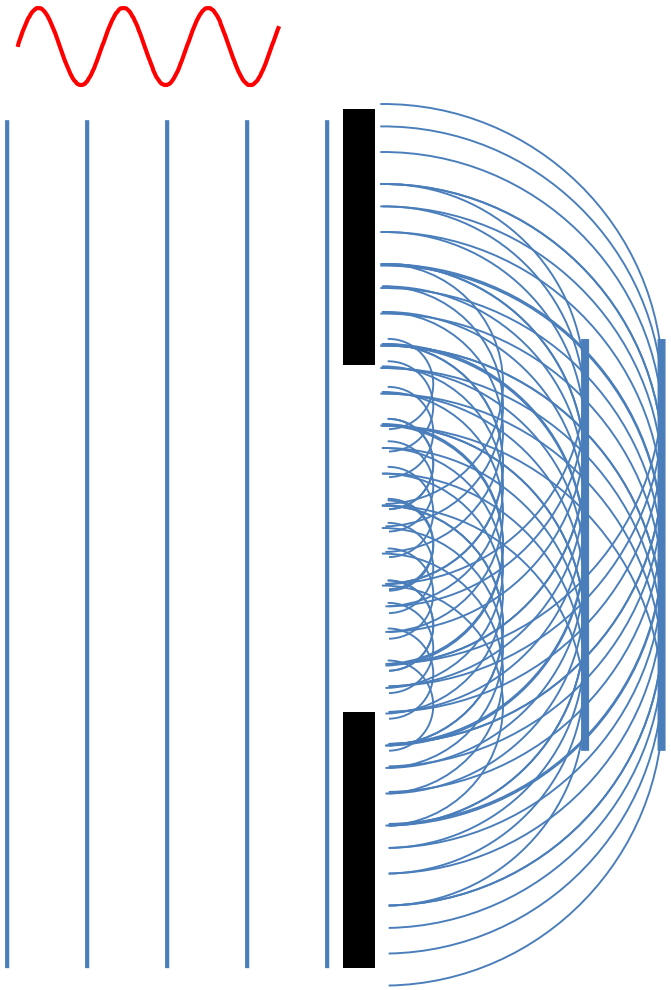
Destructive

Thin film interference

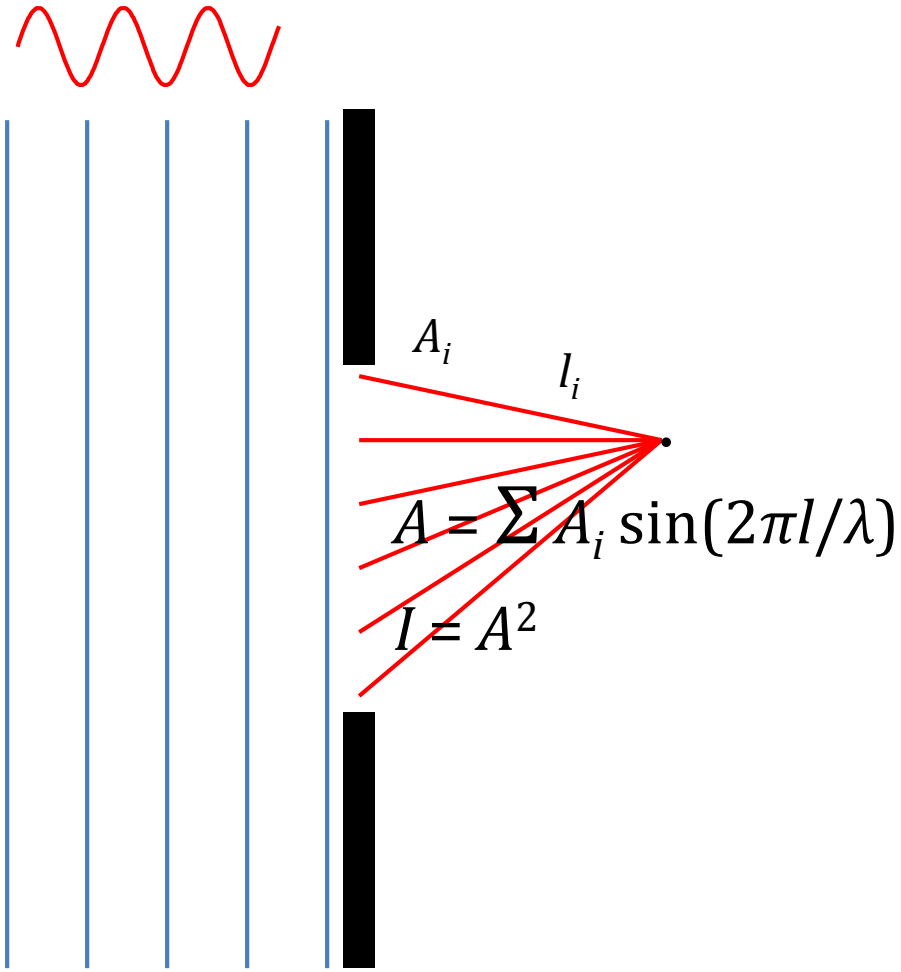


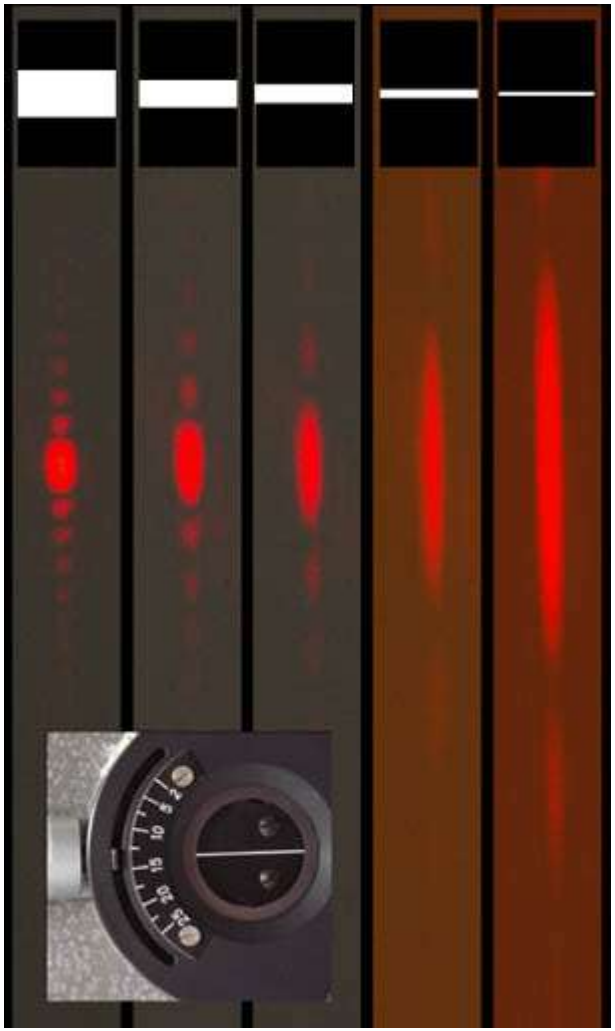
- Thickness
- Angle
- Wavelength

Light propagation = diffraction + interference



Light propagation = diffraction + interference





Light as electromagnetic waves

Maxwell's equations

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \boldsymbol{B} = 0$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

$$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} + \mu_0 \varepsilon_0 \frac{\partial \boldsymbol{E}}{\partial t}$$

Light as electromagnetic waves

Maxwell's equations

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$

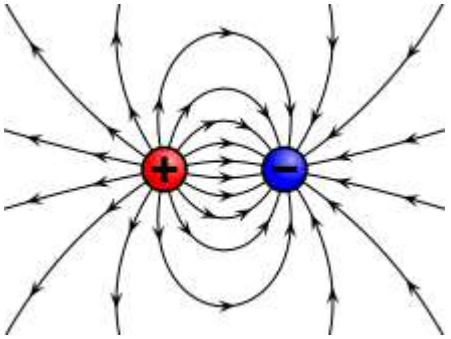
Charge density

Electric field

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

$$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} + \mu_0 \varepsilon_0 \frac{\partial \boldsymbol{E}}{\partial t}$$

Static electric field generated by charges



wikipedia

Light as electromagnetic waves

Maxwell's equations

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$

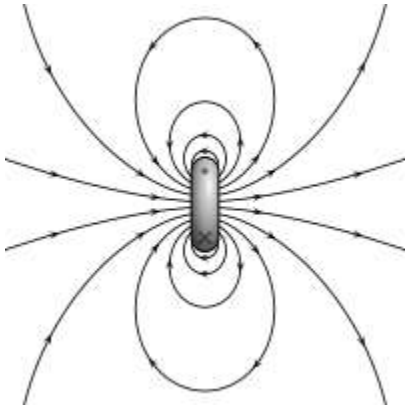
$$\nabla \cdot \boldsymbol{B} = 0$$

Magnetic field

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

$$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} + \mu_0 \varepsilon_0 \frac{\partial \boldsymbol{E}}{\partial t}$$

Magnetic force lines form closed circles.



wikipedia

Light as electromagnetic waves

Maxwell's equations

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \boldsymbol{B} = 0$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

$$\nabla \times \boldsymbol{B} = \mu$$

Rate of change

A changing magnetic field generates electric field

Light as electromagnetic waves

Maxwell's equations

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \boldsymbol{B} = 0$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

$$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} + \mu_0 \varepsilon_0 \frac{\partial \boldsymbol{E}}{\partial t}$$

Electric current

Electric current and changing electric field generate magnetic field

Light as electromagnetic waves

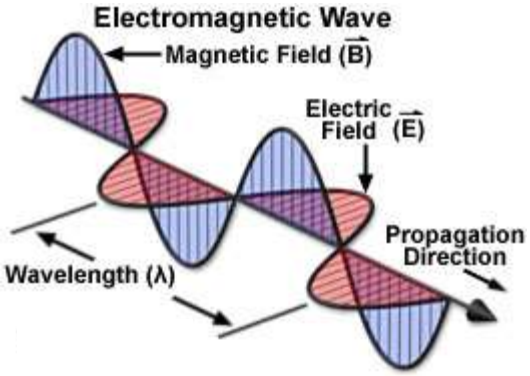
Maxwell's equations

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \boldsymbol{B} = 0$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

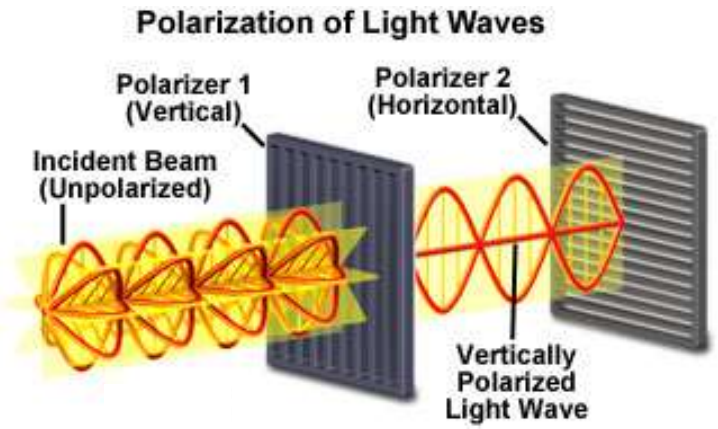
$$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} + \mu_0 \varepsilon_0 \frac{\partial \boldsymbol{E}}{\partial t}$$



Michael Davidson

Speed of light $= 1/\sqrt{\mu_0 \varepsilon_0}$

Polarization

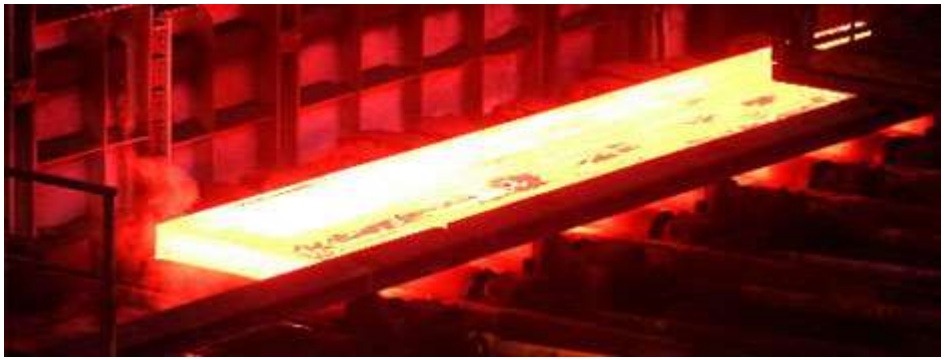


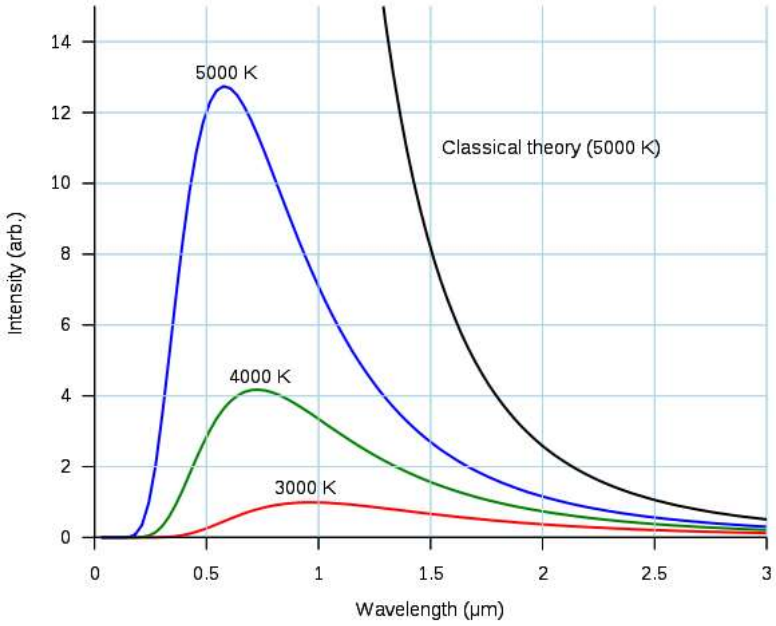
Michael Davidson

wikipedia

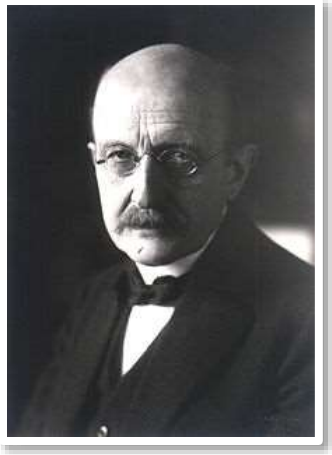
Light as particles

From blackbody emission



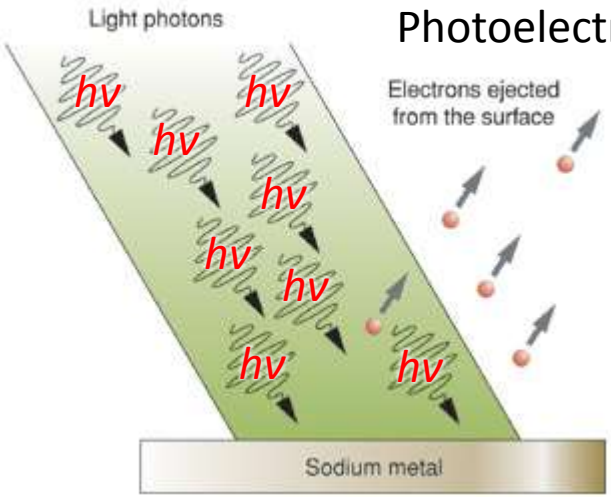


Max Planck



$$E = h\nu$$

Photoelectric effect

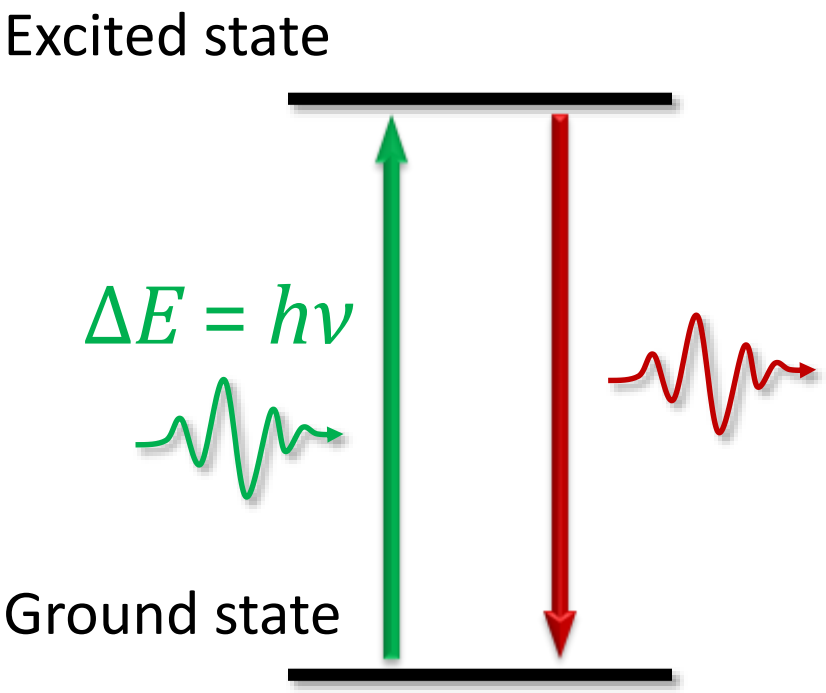


The Encyclopedia of Science

Albert Einstein

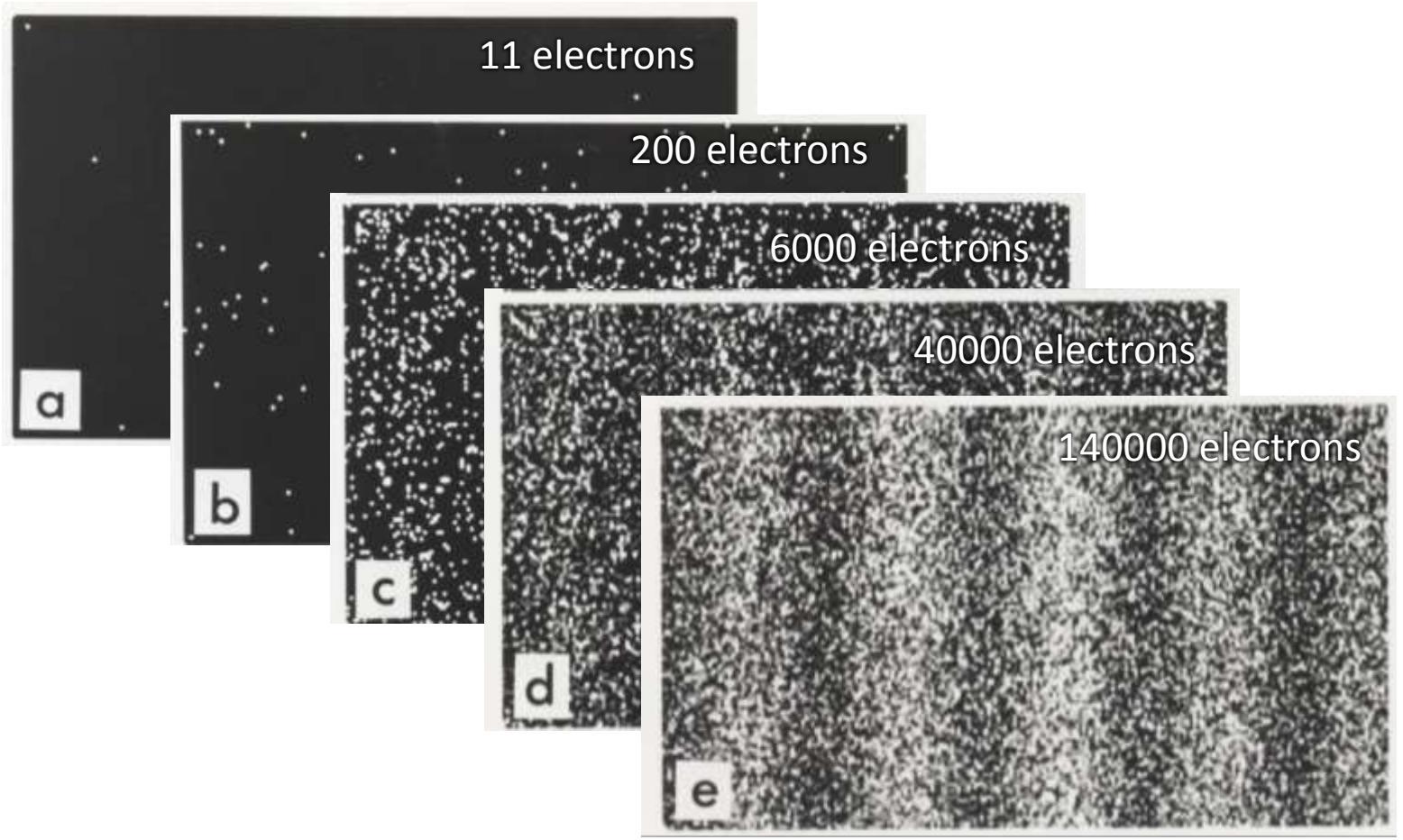
1 Einstein = 1 mole of photons

Photon: the quantized energy of light



Wave-particle duality

Double-slit experiment of electrons



Akira Tonomura, PNAS, 2005

What light really is?